

Climate-Biosphere Interactions Scope of Work

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CLIMATE-BIOSPHERE INTERACTIONS

SCOPE OF WORK

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SCOPE OF WORK

I. Introduction

This document describes the research that will be undertaken in this project over the next five years. Its purpose is twofold. First, it presents the scientific questions that must be addressed in order to answer important public policy needs concerning the potential environmental effects of global climatic change. Second, it describes the general research approaches that will be used to answer the scientific questions.

The document is organized into four sections: 1) an overview of the project, 2) a description of the research tasks that will be undertaken, 3) a discussion of the relationship of this project's research with other global change research, and 4) a budget summary.

II. General Project Overview

Policy Questions/Issues: Research in this project is designed to address the following three policy questions and issues.

1. Which regions of the world are most vulnerable to climatic change?

Global climatic change could cause major vegetation changes throughout the world, both in terms of composition and distribution. These changes could result in major economic and environmental damage on an international scale. Decision makers need to know those regions of the U.S. and the world most vulnerable to climatic change, in order for research, mitigation, and adaptation efforts to be most effective.

2. How much, and in what ways, can climate change before large and detrimental biotic impacts occur on continental and global scales? How fast can vegetation change?

Policy makers need to know how soon serious biotic impacts could occur so that mitigation efforts can be most effectively planned.

3. What is the uncertainty of future climate scenarios and projections of future vegetation patterns?

Policy makers need to know the uncertainty of future climate projections in order to justify the expense of various adaptation and mitigation strategies.

Science Questions/Research Needs: The above policy issues lead to the following science questions and research needs that this project will address.

1. How does climate influence the distribution of indicator species of major plant formations (as defined by physiognomy)? How do synoptic climate patterns influence plant distribution?

Research is required on relating synoptic climate patterns with biotic patterns, and determining the mechanisms by which climate affects the distribution of indicator species.

2. What is the relationship between the abundance of selected plant species and climate?

Ecological response surfaces need to be constructed for a wide range of plant species for use in making projections of future vegetation patterns.

3. How have individual species responded to previous climatic changes, especially rapid change? Do disturbance frequencies change significantly during periods of rapid change? Can paleoecological techniques be used to establish a paleoclimatic record independent of proxy vegetation data? How much can climate change before there are significant vegetation effects?

Biotic impacts of previous global warming events in the Holocene need to be studied, especially during time periods of rapid climatic change. Techniques for conducting these studies need to be refined.

4. How well do empirical and statistically derived global vegetation models simulate modern vegetation? Can the models be refined to include more realistic limiting climate variables, and to increase their regional precision? Can vegetation dynamics be added to these models?

Continental-scale vegetation models need to be evaluated in terms of how well they simulate vegetation and how they can be modified to increase their spatial and taxonomic precision.

5. Can the future distribution of indicator species be projected using either scenarios of changes in atmospheric circulation patterns, or quantitative estimates of limiting climatic variables?

Research needs to be conducted on techniques for estimating species distributions from either scenarios of atmospheric circulation patterns or from quantitative estimates of climate variables.

6. What will future vegetation patterns be across North America and the world in response to global warming? Where will major biome types (e.g. forests, grasslands, deserts) be located in the future?

A variety of modeling techniques need to be used to make projections of future vegetation patterns. These techniques should include an indicator species approach, ecological response surfaces, statistical continental-scale vegetation models, and hierarchical vegetation models.

7. Can a hierarchical model framework encompassing models that operate at different scales be developed so that vegetation dynamics can be realistically simulated? How should the models be linked together? How should spatial ecological process, like disturbance, be modeled?

Research will be conducted on how to link ecological and physiological models that operate at different temporal and spatial scales so that vegetation dynamics can be simulated in a realistic manner.

8. How will changes in vegetation cover affect terrestrial biophysical feedbacks (e.g. biogenic emissions, surface albedo, and sensible and latent heat flux) on continental and global scales? How can short-term changes in these feedbacks be modeled over a broad region?

Important biophysical feedbacks that are affected by vegetation need to be quantified using remote sensing and site specific measurements. Methods need to be developed on how to model transient effects of climate change on biophysical feedbacks.

9. What regional climatic patterns have been most sensitive to previous global warming trends? Is the qualitative regional response to a global warming the same regardless of the magnitude of the warming or of the forcing function that is causing the change? Are there threshold responses of climate to external forcing functions?

Research is needed on reconstructing past regional climate patterns during global warming trends, and in understanding how atmospheric circulation patterns varied during earlier warm periods.

10. How can biologically and hydrologically meaningful scenarios of future climate be generated from GCM output? How can the spatial resolution of these scenarios be improved in the short-term and in the long-term?

In the short term, principles of synoptic climatology, surface energy balance, boundary layer climatology, and regional topography will be used to increase the resolution of GCM based climate scenarios. Long-term research is needed on increasing the spatial resolution of GCMs and on embedding mesoscale models into them.

11. How well do the vegetation models generated in this project simulate vegetation?

Vegetation models will be validated using simulations of modern vegetation and past vegetation during the Holocene.

12. How well do General Circulation Models (GCMs) simulate past and present climates in terms of those climatic variables most important in determining the distribution of plants? How well do GCMs simulate atmospheric circulation patterns? What are the major uncertainties in the models, and which are resolvable and which are not?

Research is needed to evaluate how well GCMs simulate past and present climates in terms of those climatic variables most important in determining the distribution of plant species. Model uncertainties need to be evaluated in terms of which can be reduced and which can not. GCM simulations of future climate need to be evaluated in terms of how well they represent likely future atmospheric circulation patterns under warmer global temperatures.

Approach:

Research in the near term in this project will focus on the potential impact of climatic change on terrestrial vegetation on continental and global scales, as this is the broadest scale at which biotic impacts will occur. Initial projections will be equilibrium simulations of vegetation response to climatic change. Long-term research will expand to include projecting transient responses of vegetation, and detailed consideration of biophysical feedbacks to the atmosphere.

The underlying philosophy of the research approach is to use a variety of methods to 1) understand how vegetation responds to climatic change and to 2) predict future impacts of climate change. Predicting vegetation response to climatic change is a complex task, and using a variety of approaches is the best way to gain an understanding of the uncertainties in projections of future change. Briefly, methods for understanding the response of vegetation to climatic change will include focusing detailed work on important indicator species of major physiognomic classes, developing ecological response functions for a wide range of important plant species, and using retrospective studies

(historical and paleoecological) to understand how species and vegetation have responded to past climatic changes, especially rapid change. This information will be used to refine existing models and develop new models for predicting the response of vegetation on a continental scales. The modeling will be conducted in a Geographic Information System (GIS) environment, so that additional geographical data (such as soils) can be integrated into assessments, and so that estimates can be made of the direction and magnitude of changes in biophysical feedbacks.

Scenarios of future climate will be needed to drive the vegetation models. Research in this project will provide the atmospheric scientists who are developing the climate scenarios information on what climate data is needed by effects modelers, including the required temporal and spatial resolution. Also research will be conducted to a limited extent as to how the climate system could respond to higher trace gas concentrations, using historical and paleoclimatic data.

Validation of vegetation and climate models will be an important task, again using modern, paleoecologic, and paleoclimatic data.

Rationale:

Research in this project will address three critically important policy questions concerning global climatic change. Specifically, the research will 1) determine the regions of the U.S. and the world most sensitive to climatic change in terms of their biotic resources, 2) estimate how much climate can change before there are significant biotic impacts, and 3) examine the uncertainty inherent in future climate scenarios generated by GCMs. This information will enable efficient development of adaptation and mitigation strategies by indicating where those efforts are most needed. In addition, establishing thresholds of response will help determine the speed at which mitigation strategies need to be implemented. Also, establishing the magnitude of uncertainty of possible climatic changes will be critical for establishing a consensus for responding to future changes. Finally, results of this research will be invaluable for focusing more in depth future research in those geographic areas where the largest changes are likely.

This research will build on EPA expertise on identifying the response of plants to environmental stresses, and recently acquired proficiency in biogeography and paleoecology. The climatology components will be coordinated with and compliment the global climatic research being undertaken at the Atmospheric Research and Exposure Assessment Laboratory at Research Triangle Park (AREAL-RTP). Finally, the proposed GCM validation work will be coordinated with ongoing work on this area by the National Science Foundation (NSF) (e.g. the Cooperative Holocene Mapping

Project, COHMAP), and will fill an important gap in their program.

Since EPA will be a major developer of future climate scenarios for use by effects researchers, it is imperative that it be a part of GCM validation work in order to stay up to date on latest findings in this research area.

Major Science and Policy Outputs

In FY'90 a report will be prepared reviewing the strengths and weaknesses of currently available global vegetation models. The best models will be used to make projections of the future location of major forest types in North America in response to global warming, and the effects of those changes on biogenic emissions and surface albedo. In FY'91 the relative sensitivity of regions of North America to climatic change will be outlined, using a variety of approaches. In FY'92 the strengths and weaknesses of GCMs in simulating warmer global climates will be analyzed. In FY'93 the relative sensitivity of regions of the Western Hemisphere to climatic change will be determined. Also, projections will be made as to how much regional climate patterns can vary in North America before there are significant biotic impacts. The potential response of vegetation in Asia and Africa to global warming will be estimated in FY'94.

III. Research Task Descriptions

Research in this project is divided into four major tasks. Each task has as its major objective developing information or tools that are needed to make projections of future vegetation. Actual projections of impacts will be made in Task 2. Linkages between the projects are shown in Figure 1, and are discussed within each task.

A. Task 1 Sensitivity of Vegetation to Climatic Change

Policy Questions

1. Which regions of the world are most vulnerable to climatic change?
2. How much climate can change before large and detrimental biotic impacts occur on continental and global scales? How fast can vegetation change?

Science Questions

1. How does climate influence the distribution of indicator species of major plant formations (as defined by physiognomy)? How do synoptic climate patterns influence plant distribution?
2. What is the relationship between the abundance of important plant species and climate?

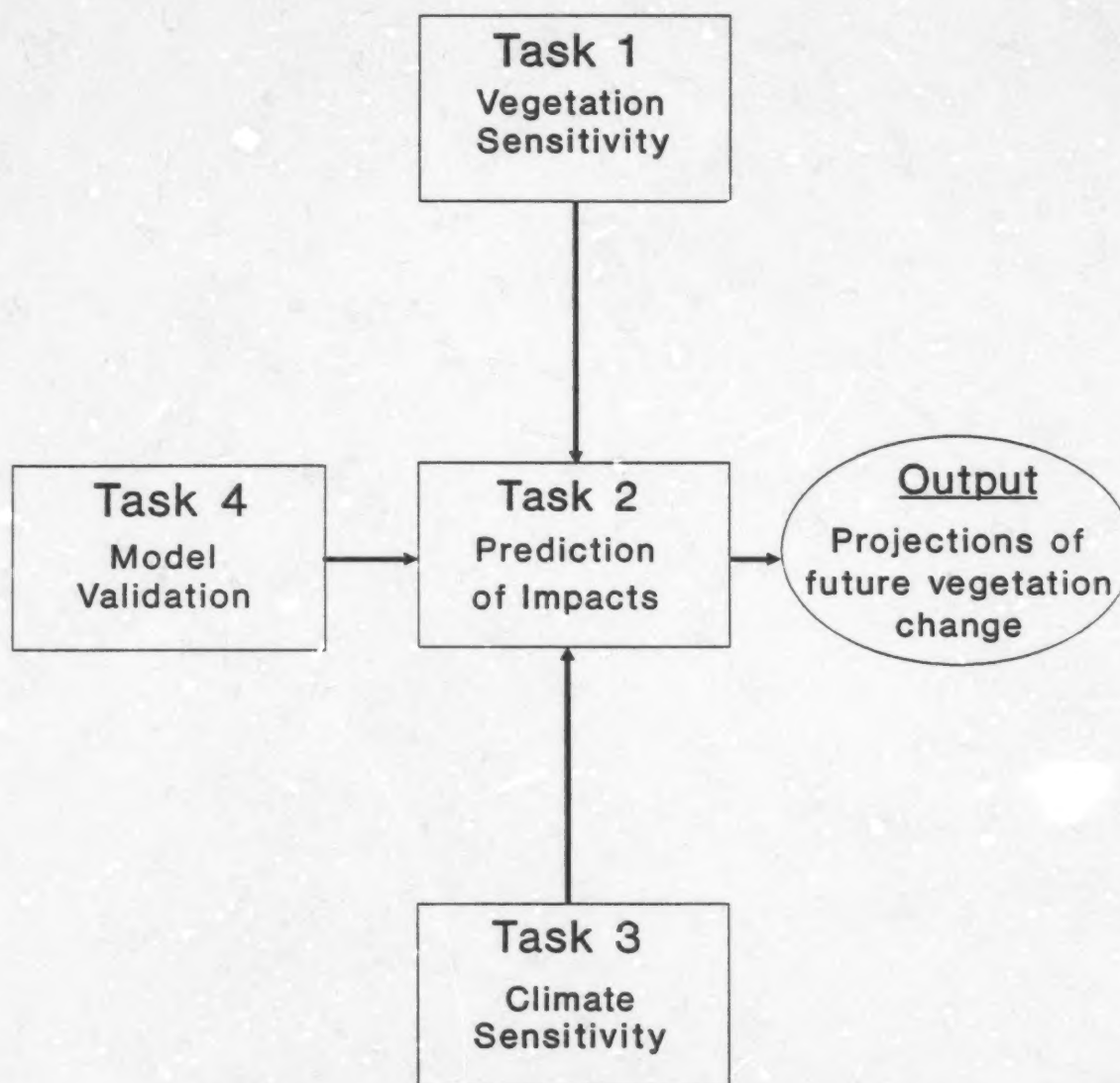


Figure 1. Major tasks of the Climate-Biosphere Interactions project. Arrows depict predominant flow of information between tasks.

3. How have individual species responded to previous climatic changes, especially rapid change? Do disturbance frequencies change significantly during periods of rapid change? Can paleoecological techniques be used to establish a paleoclimatic record independent of proxy vegetation data? How much can climate change before there are significant vegetation effects?

Approach:

Research in this task will involve developing an understanding for how climate affects the distribution and abundance of plant species, and the impact of rapid change on vegetation. Information from this project will be used in task 2 to develop predictive models of vegetation-climate relationships.

Subtasks:

1. Indicator Species (Biotic Regions)

The purpose of this subtask is to determine those seasonal climatic patterns that influence the positions of the major plant formations within the United States and worldwide. Plant formations will be defined in terms of the dominant physiognomic plant cover (e.g. broad-leaved trees). An indicator species approach will be used to accomplish this goal, as one way to establish mechanisms of the climatic control of plant formations is to use data collected on the response of representative species to climate and then extrapolating to the entire physiognomic type.

Specifically, two or more indicator species of a physiognomic type will be chosen for in depth analysis (e.g. sagebrush for shrubland and sugar maple for the deciduous forest). For a particular physiognomic type, species with different environmental sensitivities (e.g. drought tolerant versus intolerant, shade tolerant versus intolerant) and different ecological strategies (e.g. wind dispersal of seeds versus animal dispersal) will be chosen as indicators to increase the diversity of species that will be analyzed. Then the scientific literature will be searched for information relating to the response of that species to climate. Information which will be of particular use will be long term establishment data and physiological data on the response of the species to particular climate extremes. The goal of this literature search will be information suggesting weather patterns that prevent the completion of a species reproductive life cycle (e.g. late frosts killing flower buds, or spring droughts preventing seedling establishment). An additional important source of information that will be used to postulate climatic effects on individual tree species is existing tree-ring data.

Information on the possible effects of climate on changing

the outcome of competition between species (which could confound the climatic analyses) will also be acquired, as well as information on how changes in soils could affect species distributions.

After the review of the literature, hypotheses will be proposed as to how climate limits the distribution of the indicator species. Support for these hypotheses will vary depending on the amount of information in the literature on a particular species. An indirect test of the hypotheses will be conducted by mapping the limiting weather pattern and comparing it with the range of the indicator species. Congruence of the two will support the climatic hypothesis.

In order to rigorously test these hypotheses, field or greenhouse experiments will be conducted on several of the indicator species. Field studies will involve such experiments as germination trials, seedling transplants beyond the species range limits, and monitoring of flowering and seed set of populations at the species' range limit. This work is inherently long-term, with three year studies a minimum length. Consequently, these experiments will be tied into existing long-term studies, such as at NSF's Long-Term Ecological Research (LTER) sites.

A specific set of climatic analyses will also be part of this task, specifically 1) mapping the climate patterns (e.g. summer rainfall in the Southwest) suggested as controlling the range limits of the indicator species, and 2) then analyzing how atmospheric circulation patterns determine these regional climate patterns.

Mapping regional climate patterns will involve using geographic information analyses of climate data. Spatial statistical procedures will be used to interpolate between climate stations. Once the climate maps have been constructed, the range limits of the indicator species will be overlaid on them in order to determine if changes in the magnitude or seasonality of the hypothesized limiting climate variable correspond with the species range limits. If they do not work in the first part of this subtask will be repeated, focusing on other possible limiting climate variables or possible confounding effects such as competition or soils. If the patterns do overlap, the following work will be conducted.

The identified seasonal weather patterns important in limiting plant distributions will then be related to upper air circulation patterns using principles of synoptic climatology. An example of the type of relationship which will be characterized is the connection of the Southwest Monsoon with changes in the seasonal location and strength of the subtropical high pressure systems, particularly the Bermuda High. Much of this information is available in the literature and additional analyses will be

coordinated with ongoing research in synoptic climatology at AREAL-RTP. Techniques that will be used to determine these relationships will include correlation analyses of atmospheric circulation data and regional precipitation and temperature data and other appropriate statistical techniques.

Developing an understanding of how global atmospheric circulation patterns influence species distributions will enable qualitative projections of future biotic distributions based on our understanding of how circulation patterns could change in the future. This will be discussed further in Task 2.

2. Ecological Response Surfaces

The indicator species approach is useful for establishing the physiologic, morphologic or ecological mechanisms that limit plant distribution, but it is limited in several ways. First, the climate relationship is limited to species range boundaries, rather than to abundance. Second, the analysis is labor intensive, especially if experiments are conducted. Third, compositional changes of major physiognomic types can not be determined using the indicator species approach at this time.

An alternative approach which does not have these limitations and is complementary to the indicator species approach, is the ecological response surface methodology. In the response surface approach, abundance of a species at specific points within its range are plotted against a number of climate variables at those same points (e.g. mean July temperature, mean January temperature, and total annual precipitation). A response surface of that species to these climate variables is generated using locally weighted regression analyses (Figure 2). This approach is correlational, but can be completed relatively rapidly for a number of species for which abundance data is available. The approach is powerful in a predictive sense, since the surfaces represent how two or more climatic variables control equilibrium species abundances. Furthermore the approach is complementary to the indicator species approach, in that the results from that approach can be used to identify those climate variables that are important in controlling species distributions and hence should form the independent variables for the response surface.

Once response surfaces have been calculated, they can then be used to predict species abundance given a climate scenario (this method will be described in more detail in Task 2).

This approach has been effectively used to relate pollen abundances in eastern North America to climate. In this subtask, response surfaces will be constructed for tree species abundances using U.S. Forest Service data in the short-term, and data from remote sensing and other sources in the long-term.

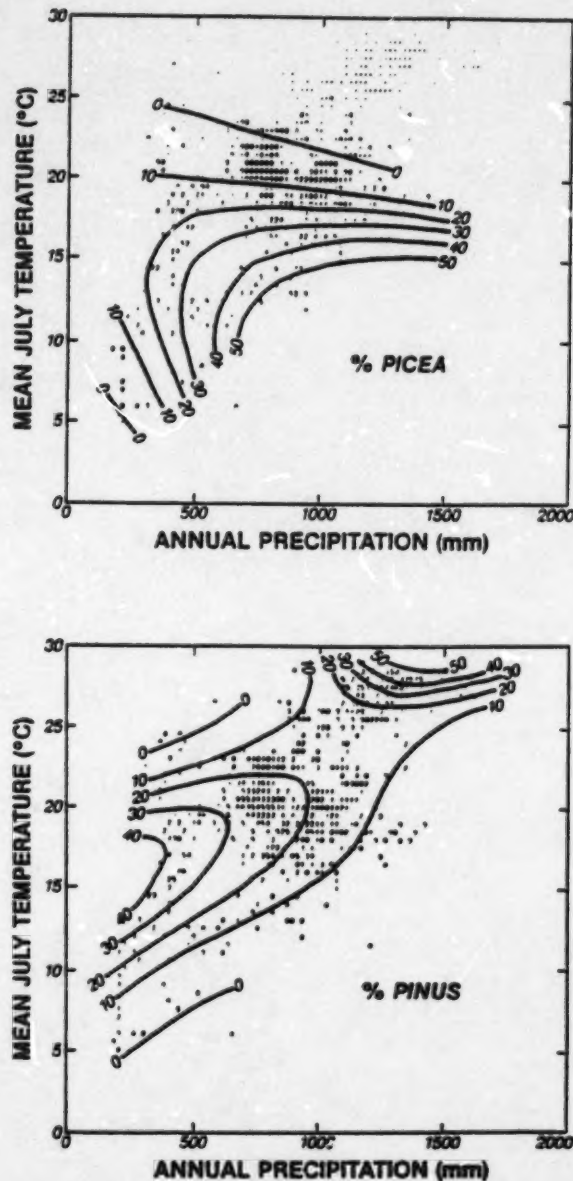


Figure 2. Example of ecological response surfaces for spruce (*Picea*) and pine (*Pinus*). These surfaces are based on modern pollen percentages of these genera. Similar surfaces can be constructed for other indices of plant abundance, such as basal area or growing stock volume. These surfaces were taken from the journal article, Climatic response surfaces from pollen data for some eastern North American taxa, P.J. Bartlein, I.C. Prentice, and Thompson Webb, III. Journal of Biogeography 13: 35-57.

3. Past responses to climatic change.

The purpose of this subtask is to determine the sensitivity of biota to climatic change, especially the impacts of rapid warming using retrospective studies. A key research area will be determining the threshold response of biota to climatic change.

Historical data on species distributions and abundance can be used to understand how species respond to climatic change. It is particularly useful in evaluating hypotheses for how climate controls range limits, because actual data on species response to climate can be obtained from historical data (e.g. years of seedling establishment can be related to variation in seasonal rainfall patterns). Sources of data will include archival records at sites where long-term research has been performed, and temporal sequences of photographs. Tree-ring width and density, which record the response of tree growth to seasonal and annual climate variability, will also be an important source of information on climatic effects on species growth.

Paleoecological studies will be used to gain an understanding of how vegetation in general and indicator species responded to past climatic changes. The extensive data base for North America and Europe will be an important source of information on vegetation response to climatic change, and the mid-Holocene warm period will provide information on possible impacts of global warming on vegetation.

New research will focus on the impacts of rapid climate change. This will initially entail identifying regions and time periods where climate changed rapidly during the Holocene, and then conducting intensive studies at a few sites within these regions. Only sites at which decadal events can be resolved (e.g. sites with annually laminated sediments or high sedimentation rates) will be chosen for study, so that high resolution records of system response to rapid change can be obtained. Using a number of different proxy records (e.g. pollen, diatoms, sediment chemistry, isotopic) will enable a detailed reconstruction of the impacts of rapid change. Key questions that will be answered by these studies include how fast can a species invade and become dominant at a particular site, how fast can one type of vegetation be replaced by another (e.g. grasslands by desert), what processes affect the rate of invasion (e.g. does fire increase the rate of vegetation change?), how fast do soils change in response to changes in vegetation, and what are the characteristics of vegetation in a rapidly changing environment (e.g. are the dominant trees early successional, shade intolerant species?).

The threshold question, that is how much and in what ways can climate change before there is a significant vegetation response, will be addressed using similar analyses. Specifically,

the paleoclimate record will be established first by using a proxy indicator that responds rapidly to climatic change (e.g. diatoms, and ostracods). Then the vegetation record of change will be compared with the climate record to determine vegetational response times. Initial work will proceed on a case study basis, focusing on selected forested ecosystems. Consideration of possible lags in vegetation response (e.g. limitations of seed dispersal) will have to be considered in this analysis.

Major Objectives and Products

Research in this task will result in a more complete understanding of how climate influences the distribution and abundance of plant species, and lead to the refinement of techniques used to predict vegetation response to climatic change (as described in Task 2).

B. Task 2 Prediction of Vegetation Impacts

Policy Question

1. Which regions of the world are most vulnerable to climatic change?

Science Questions

1. How well do empirical and statistically derived global vegetation models simulate modern vegetation? Can they be refined to include more realistic limiting climate variables, and to increase their regional precision? Can vegetation dynamics be added to these models?
2. Can the future distribution of indicator species be projected using either scenarios of changes in atmospheric circulation patterns, or quantitative estimates of limiting climatic variables?
3. What will future vegetation patterns be across North America and the world? Where will major biome types (e.g. forests, grasslands, deserts) be located in the future?
4. Can a hierarchical model framework encompassing models that operate at different scales be developed so that vegetation dynamics can be realistically simulated? How should the models be linked together? How should spatial ecological process, like disturbance, be modeled?
5. How will changes in vegetation cover affect terrestrial biophysical feedbacks (e.g. biogenic emissions, surface albedo, and sensible and latent heat flux) on continental and global scales? How can short-term changes in these feedbacks be modeled over a broad region?

Approach:

The main goal of this project will be to develop the capability to project future vegetation distributions given scenarios of future climate. In the short-term, currently available, statistically based vegetation models that predict vegetation over continental and global scales will be evaluated as to their ability to simulate present vegetation. The best models will be used to make some initial projections of the location of biomes under warmer global conditions.

In the longer term, other models and techniques will be used to make projections (indicator species and response surface techniques) and a new modeling framework will be developed to model transitory responses (hierarchical modeling). The focus here will be on developing dynamic models, so the transitory effects of climatic change on vegetation can be analyzed. Changes in biophysical feedbacks will be estimated for changes in vegetation cover.

Subtasks:

1. Statistical climate-vegetation models

Several empirical and statistically based global vegetation models currently exist. These models are either driven by climate classification schemes (e.g. Holdridge) or on statistical relationships between plant physiognomic forms and modern climate (e.g. the model developed by E.O. Box 1981, described in his book, Macroclimate and plant forms: An introduction to predictive modeling in phytogeography). As a first step these models will be evaluated in terms of how well they simulate modern vegetation. The best models will be used to make initial projections of the equilibrium vegetation response to future climatic change.

In the longer term, more extensive model modification and development will take place. In particular, currently available models will be modified using information obtained from the indicator species and response surface subtasks to incorporate the climate variables that are important in controlling range limits. An example of a change that may have to be made to some of the current models is to add seasonality of climate, as changes in seasonality can be an important determinant of vegetation boundaries. Additional modifications will be made to the models based on the earlier evaluation of how well they simulate present vegetation. Consideration will have to be given on whether to include direct effects of carbon dioxide on vegetation. Whether to include it or not will be based on an analysis of currently

available experimental data on carbon dioxide impacts on plant species. Research will also focus on determining the spatial precision of these models, and on methods to improve that precision.

Also in the long-term, vegetation models based on remote sensing information will be refined and used to make global scale vegetation projections.

Finally, research will be conducted on if vegetation dynamics could be incorporated into these models. That is, the models currently project equilibrium vegetation response, which could take several hundred years after a given climatic change. In order to project vegetation response to climate change in the next century such factors as migration rates need to be considered in these models. Other important considerations will be land-use patterns, and soil effects. Another approach at developing dynamic modeling is described in subtask 4.

2. Physiognomic predictions using indicator species

Another approach to making vegetation projections goal is to develop a modeling framework based on work in the indicator species subtask which will relate atmospheric circulation patterns with biotic distributions. Research is needed on whether quantitative models can be developed that relate atmospheric circulation patterns with the distribution of indicator species. If the development of these models is successful, projections of the future distribution of physiognomically based vegetation units could be determined using scenarios of changes in atmospheric circulation patterns, rather than using quantitative estimates of temperature and precipitation that at this time are highly uncertain on a regional-scale.

As a minimum, projections can be made of the location of indicator species in the future, using information on the future spatial pattern of limiting climatic variables. Extrapolation from the indicator species to the distribution of physiognomic types can then be made. Using indicator species to project future locations of specific vegetation types is inappropriate, however. The fossil record indicates that species behaved individualistically in the past in response to climatic change. Vegetation regions did not "move" intact across the landscape. In fact, in the past vegetation types formed which do not have modern analogues. Similarly, new vegetation types could form in the future in response to climatic change. Consequently, indicator species can only be used to predict locations of broadly defined, physiognomic vegetation types.

3. Vegetation predictions using response surfaces

Using response surfaces as a tool for making future

vegetation descriptions is essentially similar to the statistically based vegetation models (e.g. Box 1981), but is more taxonomically precise. Application of the surfaces involves several steps. First, values of the independent climate variables used in the response surfaces must be obtained for specified geographic locations in the region of interest. This information will be obtained from future climate scenarios. Then the response surfaces are used to translate estimates of climate variables into estimates of species abundance at specified locations. Regional vegetation maps can then be produced by integrating the results at individual locations using spatial analytical techniques (e.g. krieging).

4. Hierarchical. ecological models

The above techniques of modeling have several major drawbacks, two of which limit the accuracy of their projections. First, they are primarily equilibrium models, and don't factor in such important phenomena as migration rates. Second, they ignore some important ecological processes that could be important in the future response of vegetation to climatic change, such as disturbance. Thus an alternative modeling framework needs to be developed to address these limitations.

In this subtask, such an alternative model will be formulated in cooperation with other Global Team projects. It will be hierarchically based, in that important ecological and climatological processes will be modeled at the most appropriate scale (i.e. regional, landscape, stand, and individual), using as input necessary information from lower or higher scale models. The results from these calculations will then be used as input data to other models to produce dynamic estimates of vegetation change. For instance, disturbances such as fire are landscape and regional-scale processes and should be modeled as such. However, to determine fire frequencies, landscape models need information from stand level models on fuel levels and species composition. In turn, fire probability within a landscape can then be input into stand level models to produce actual estimates of vegetation change.

Components of this hierarchical model will need to be embedded in a geographic information system framework, in order to integrate data over a landscape or region. This will be accomplished by gridding a landscape and performing needed calculations at gridpoints. Geographic information analysis will be used to distribute the results spatially, using additional information such as soil type and elevation. A flow chart of one possible conceptualization of this hierarchical model is shown in Figure 3. Depicted in the figure are different scale models and how input and output between models could flow in order to project vegetation change.

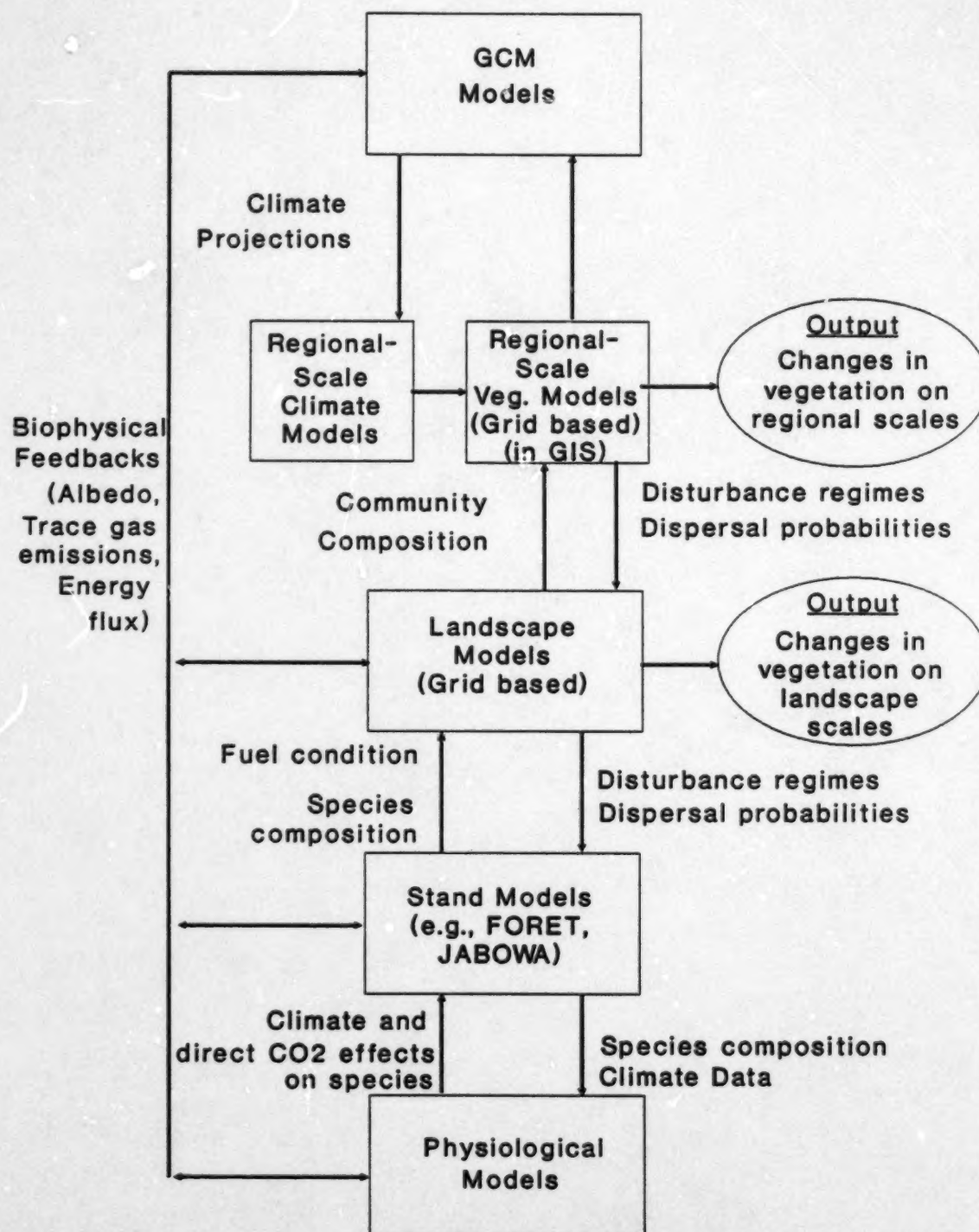


Figure 3. Conceptualization of hierarchical vegetation model.

As mentioned, this model development will be coordinated with the research in the Global Team on forests, hydrology, marginal lands, and agriculture. These other projects will supply process level models at the stand and individual plant level, and this project will develop the regional-scale models and linkages to stand level models.

5. Biophysical feedbacks

Biophysical feedbacks to climatic change could have significant effects on regional and global climates. Research in this subtask will focus on making regional predictions of changes in biophysical feedbacks as far as they are impacted by changing vegetation. Initial calculations will be based on correlations between modern vegetation and the process or character of interest (e.g. surface albedo). Remote sensing techniques will be used where applicable to make these correlations across broad regions. These correlations will be used together with estimates of vegetation change to produce estimates of change in feedback processes. Since the vegetation model output will be in a GIS framework, making areal estimates of changes in feedbacks will be straightforward using a correlational approach.

The above results will again be based on equilibrium conditions, which as discussed, aren't realistic over the next several hundred years. To analyze some of the transient phenomena that may occur as vegetation changes (such as major forest fires increasing the release of carbon dioxide and other volatile gases to the atmosphere, or simply massive tree mortality), appropriate models will be incorporated into the hierarchical model in order to predict short term changes in feedbacks. For instance, biogeochemical or physiological models could be included to provide estimates of non-equilibrium changes in trace gas fluxes. These changes could be caused by such factors as shifts in the balance between respiration and photosynthesis on regional-scales.

Major Objectives and Products

Research in this task will produce estimates of continental-scale vegetation change in response to climatic change using several methods. These projections will enable an estimation of which regions could be most sensitive to global change. The effects of rapid climate change on vegetation will also be determined in this project, including possible threshold effects. Changes in biophysical feedbacks will also be estimated on a continental scale.

C. Task 3 Regional Sensitivity to Climatic Change

Policy Question

1. Which regions of the world are most vulnerable to climatic change?

Science Questions

1. What regional climatic patterns have been most sensitive to previous global warming trends? Is the qualitative regional response to a global warming the same regardless of the magnitude of the warming or of the forcing function that is causing the change? Are there threshold responses of climate to external forcing functions?
2. How can biologically and hydrologically meaningful scenarios of future climate be generated from GCM output? How can the spatial resolution of these scenarios be improved in the short-term and in the long-term?

Approach:

Sensitivity to global climate change is both a function of the relative stability of regional climates in relation to global climate change and the relative stability of species to a given climatic change. Research in Task 1 will focus on biotic sensitivity. Research in this task will focus on climate sensitivity, in terms of understanding how regional climate patterns vary with respect to changes in overall global climate. Research in this task will also focus on helping developing regional-scale climate scenarios from GCM scenarios. This will entail interacting with scenario development researchers at AREAL-RTP by providing them with information on the type of climate data that effects researchers need in order to drive their models.

Subtasks:

1. Regional Climate Sensitivity

The purpose of this task is to determine the sensitivity of regional climate patterns to global warming, and how atmospheric circulation patterns have varied in the past under warmer global conditions. Research in this subtask is specifically designed to answer the scientific questions posed above concerning the relationship between global circulation patterns and regional climates.

Three types of data will be used in this analysis, paleoclimatic, historic (instrumental), and GCM based scenarios of future climate. Time periods of interest in the past will include

the end of the mid-Holocene warm period (focusing at about 6000 years B.P. to avoid the climatic effects of the Laurentide ice sheet which was particularly strong earlier in the Holocene), the last 1000 years as reconstructed from tree rings, and the period of global warming between 1900 and 1940. The mid-Holocene period is of interest because global temperatures were about 1° C higher than they are today. The record of the last 1000 years is useful because one can establish from it the natural variability of climate on top of which a trace-gas induced warming would be imposed. Finally, the instrumental record for the period between 1900 and 1940 provides a much more detailed record of a global warming, including direct measurements of atmospheric circulation patterns.

The utility of using past data and GCM results is that they can be compared to determine the similarity of regional climate patterns during periods of warmer global climates. For instance, if the future scenarios resemble previous global warm periods our confidence in projecting future warmer climates will increase. Comparison of atmospheric circulation patterns in the past and those projected for the future will be of prime importance in this analysis. It is recognized that past periods of warmer temperatures can't be used as strict analogues, because the ultimate cause of these warmer periods was something other than an increase in radiatively important trace gases.

The historic and GCM data analyses will be conducted by AREAL-RTP, with research in this task focused on the paleoclimatic analyses. The paleoclimatic analyses will involve synthesizing and interpreting existing data sets, and conducting selected case studies where new paleoclimatic data would be particularly useful. Both terrestrial and marine data will be considered in the paleoclimatic reconstructions. In the case studies, use will be made of the information gathered in task 1 on the indicator species. Specifically, since information will be gathered on how modern climate controls the range of those species, determining the paleogeography of these species will enable a reconstruction of the climate patterns that persisted in the past.

2. Generation of Regional-Scale Climate Scenarios

The spatial resolution of output from GCM models is too coarse for direct input into most if not all effects models. The temporal resolution of these models also tends to be too coarse for many effects models. Output from this subtask area will serve to supply those researchers generating future climate scenarios information on the spatial and temporal resolution of climate data required by effects researchers. Research will also focus on helping climate researchers and effects modelers in developing tools to refine resolution of the scenarios, using principles of synoptic climatology, surface energy balance, boundary layer climatology, and regional topography.

Major Objectives and Products

Results from this project will increase our understanding of the natural variability of climate and of atmospheric circulation patterns during global warm periods. Research in this project will also aid the development of regional-scale climate scenarios needed by effects researchers.

D. Task 4 Model Validation

Policy Question

1. What is the uncertainty of future climate scenarios and projections of future vegetation patterns?

Science Questions

1. How well do the vegetation models developed in Task 2 simulate vegetation?
2. How well do GCMs simulate past and present climates in terms of those climatic variables most important in determining the distribution of plants? How well do GCMs simulate atmospheric circulation patterns? What are the major uncertainties in the models, and which are resolvable and which are not?

Approach:

The uncertainty inherent in the vegetation projections and climate scenarios needs to be investigated in order to establish the amount of confidence that policy makers can place on future projections of climatic impacts. Research in this task will focus on validating and testing models used in the other tasks.

Subtasks:

1. Vegetation model validation

Vegetation model validation will entail comparisons of simulations of present day vegetation with the actual vegetation, and also simulations of past vegetation with actual data on past vegetation. The model evaluation using modern data will involve using maps of continental and global scale vegetation or data from remote sensing on current distribution of vegetation.

The rationale for simulating past vegetation is that vegetation changed significantly over the past 18,000 years in response to climatic change. Vegetation models, if they will be of any use in making future predictions, should be able to simulate these past vegetation changes. Paleoclimatic data to drive these simulations will come from already completed runs of

the NCAR Community Climate Model. It is recognized that discrepancies between simulated vegetation and actual vegetation could be due to either problems with the vegetation models or in the climate model. Close analysis will be given to those time periods and regions where discrepancies appear, to try and ascertain which model the problem originate from.

2. Climate model validation

GCMs will be used to simulate paleoclimates during the mid-Holocene, and the results compared with proxy data. Simulating past climates and comparing the results with actual data is the only way to test the model's ability to simulate climate under conditions different from today's. A key area of comparison will be on simulated versus observed atmospheric circulation patterns, as it is at this scale that GCMs should perform the best. New paleoclimatic data will be collected where essential for validating the GCM output.

Several different GCMs will be used in this analysis. This will provide additional information on the relative strengths and weaknesses of the models, especially in regard to how they model specific climate processes. Findings from these analyses will promote the refinement of GCMs, and efforts will be made to ensure that members of the GCM community are involved with the data-model comparisons.

Another approach will be to compare the general atmospheric circulation patterns projected by the GCMs for the future, with those patterns that persisted during earlier global warm periods. If the scenarios produced by the GCMs make sense in terms of our understanding of synoptic climatology, then our confidence in them will increase.

This research will proceed in close collaboration with AREAL-RTP and existing model validation research (COHMAP).

Major Objectives and Products

Output from this project will include assessments as to how well the vegetation models used in Task 2 simulate vegetation. Also, an evaluation will be made of the uncertainties involved in using GCMs to simulate climate, and which of those uncertainties are resolvable and which are not. Finally, an evaluation will be made as to how well GCMs simulate atmospheric circulation patterns, especially during global warming trends.

IV. Relationship to Other Research

Research in this project will need to be tightly coordinated with other programs within the Corvallis Global Team, EPA, and with other federal agencies. Key areas of cooperation are discussed here.

Much of the output from this project will be complementary to the other projects within the Global Team. Whereas the other projects will primarily operate at regional and local scales, output from this project will be at a continental-scale. As a result of this scale difference, the results from this project will be of a broader scale and lower resolution than output from the other projects, which will be at a finer scale with higher resolution. The continental scale results will be useful for determining the relative sensitivity of regions and vegetation to climatic change. This information can be then used by the other projects in determining intensive study sites. This project will place regional results in a broader geographical context. Also, this project will help develop the hierarchical vegetation modeling approach with the forest effects and marginal lands projects. Finally, the paleoecological information gathered in this project will be useful in the context of understanding how ecosystems have responded to past climatic changes.

Within EPA, coordination is essential in the analysis of historic climate data, the validation of the models used in creating the climate scenarios, and the generation of regional-scale climate scenarios. The historic climate analyses will be primarily conducted by AREAL-RTP, with input from this project as to what climate variables are of most biological relevance (e.g. frequency of frosts). In the validation research, coordination again will be with AREAL-RTP. A possible role for them is to summarize the atmospheric circulation patterns simulated by the models for the past. ERL-C would work together with them at comparing the proxy data with the model data. Finally, ERL-C will assist AREAL-RTP in generating regional-scale climate scenarios.

Outside of EPA, coordination will involve research sponsored by the Department of Energy (DOE), NSF, NASA, the International Institute for Applied Systems Analysis (IIASA), and the International Geosphere-Biosphere Program (IGBP). One area of coordination will be in the model validation research, which is currently being funded by NSF and DOE. The COHMAP research group is receiving much of that support, and research in this project will be coordinated with their efforts. An additional area of cooperation will be with the global vegetation modeling group at IIASA.

V. Budget

Fiscal Year	90	91	92	93	94
I. Task 1 Vegetation Sensitivity to Climatic Change					
1. Indicator species (biotic regions)	150	200	300	300	300
2. Ecological response surfaces	100	100	150	150	150
3. Past responses to climate change	0	100	200	300	300
II. Task 2 Prediction of Vegetation Impacts					
1. Statistical climate-vegetation models	150	150	150	150	150
2. Physiognomic predictions	0	75	100	100	100
3. Response surfaces	50	100	100	150	150
4. Hierarchical ecological models	0	75	100	150	150
5. Biophysical feedbacks	0	0	50	100	250
III. Task 3 Regional Sensitivity to Climatic Change					
1. Regional climate sensitivity	0	0	150	250	350
2. Regional-scale climate scenarios	50	100	150	150	150
IV. Task 4 Model Validation					
1. Vegetation model validation	50	150	150	150	150
2. Climate model validation	0	0	100	300	500
TOTAL	550	1050	1700	2250	2700